Cooperative Network Coding for Wireless Ad-Hoc Networks

GLOBECOM 2007

Chi-Han Lin

Jan. 17, 2008

Outline

- Introduction
- Motivation
- Relay protocol and modulation schemes
- Simulation
- Conclusions

Introduction

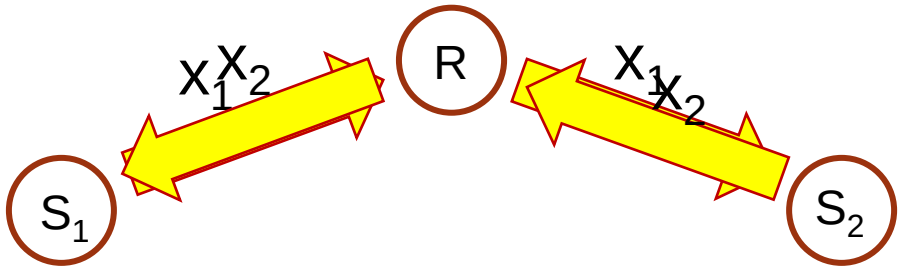
- To provide robust and efficient communication, cooperative communication and network coding are useful.
- Most existing studies focus on the performance of the two schemes separately.
- This paper investigates the performance of system that combines them tightly together.

Introduction

- In network coding, the relay will combine the information from different sources and forward the processed information to destination.
- This paper develops a new cooperative network coding scheme.
- The results show that the new scheme can significantly improve the performance over traditional schemes.

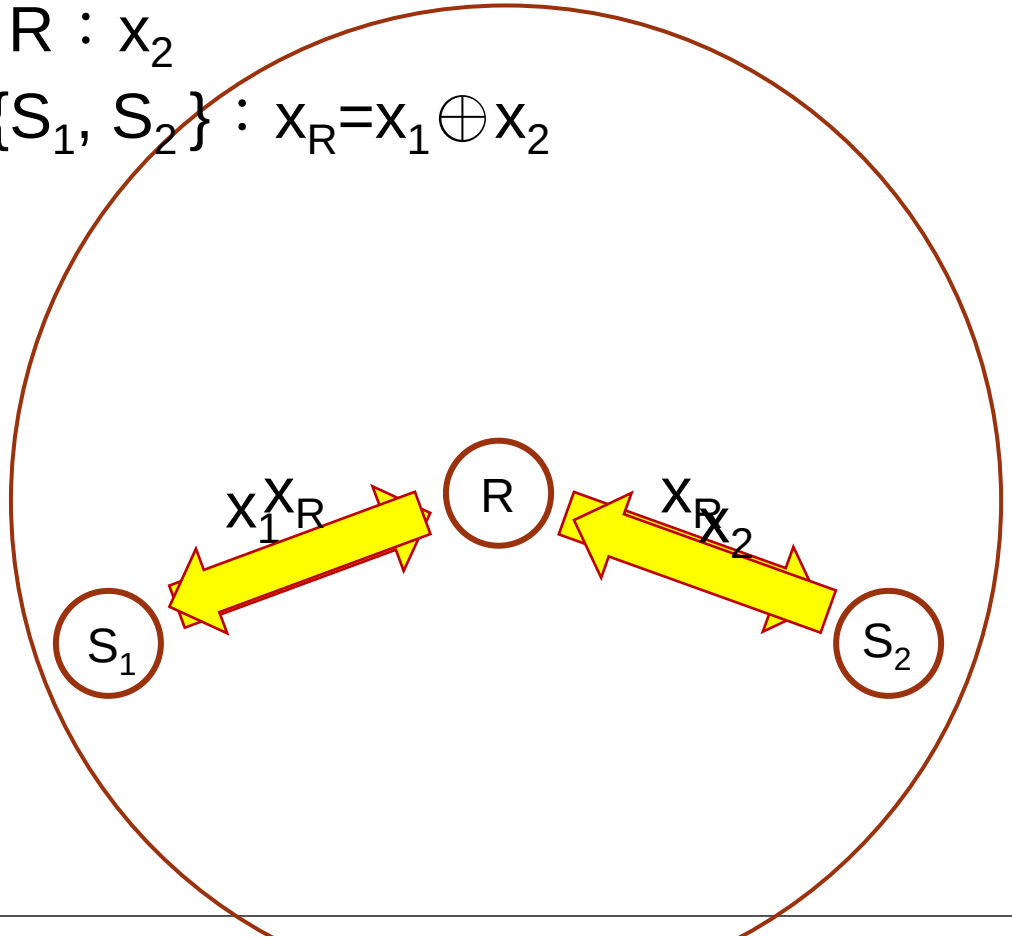
Motivation

- For information exchange, the traditional relay schemes may take four steps：
  - $S_1 \rightarrow R : x_1$
  - $R \rightarrow S_2 : x_1$
  - $S_2 \rightarrow R : x_2$
  - $R \rightarrow S_1 : x_2$



Motivation

- The network coding relay may take three steps：
  - $S_1 \rightarrow R$：x_1
  - $S_2 \rightarrow R$：x_2
  - $R \rightarrow \{S_1, S_2\}$：$x_R = x_1 \oplus x_2$

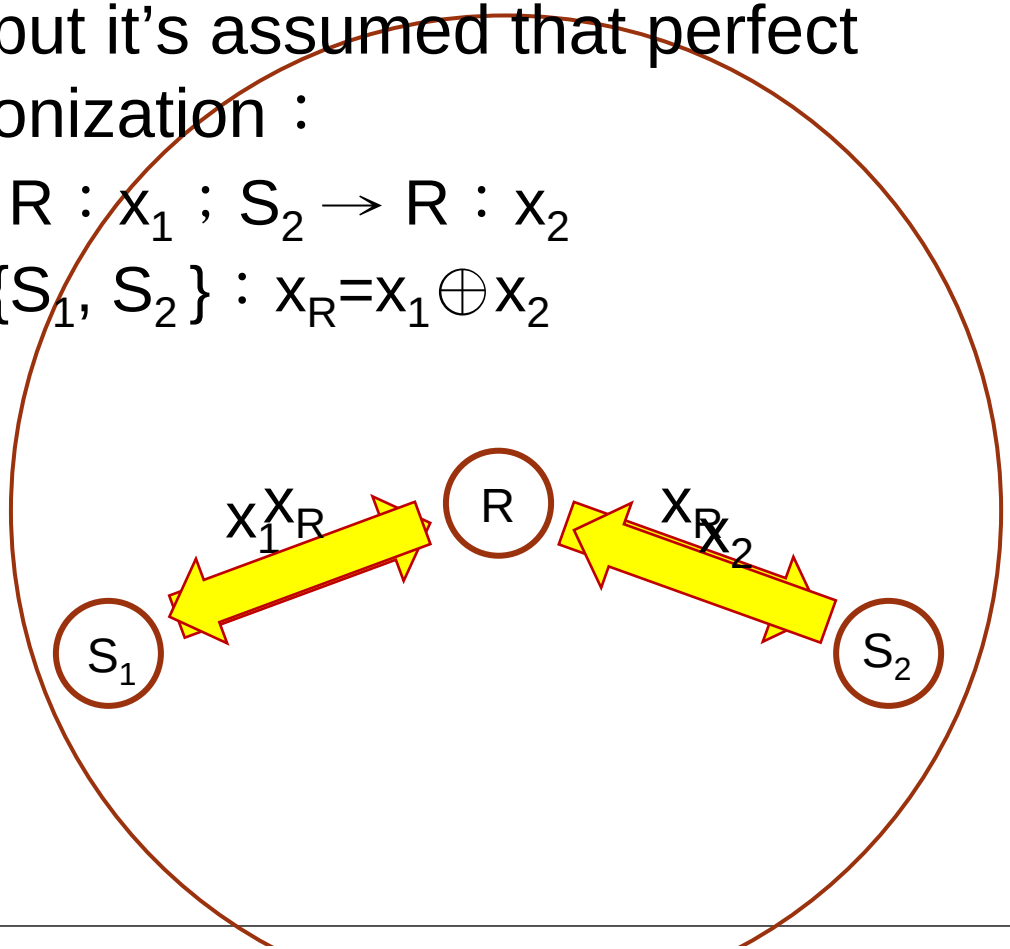


Motivation

- Since node S_1 has the a priori information of x_1, S_1 can decode x_2 through the modulo operation $x_2 = x_R \oplus x_1$.
- The network coding scheme reduces one time slot for the information exchange.
- And fully exploit the broadcast benefits of wireless channel, which is always ignored in previous designs.

Motivation

- A further improvement was developed in [11], where the information exchange may take two steps, but it's assumed that perfect synchronization :
  - $S_1 \rightarrow R : x_1$; $S_2 \rightarrow R : x_2$
  - $R \rightarrow \{S_1, S_2\} : x_R = x_1 \oplus x_2$



Motivation

- The two-step scheme enables transmission from both S_1 and S_2 over the same frequency within the same time slot.
- But the signal from S_1 and S_2 will interference each other and increase the symbol error rate.
- However, as shown in [11] the throughput will increase because of the reduction of one time slot.

Relay protocol and modulation schemes

- Case 1：One relay system
  - Amplify-and-Forward (AF)：
    - $S_1 \rightarrow R$：x_1；$S_2 \rightarrow R$：x_2

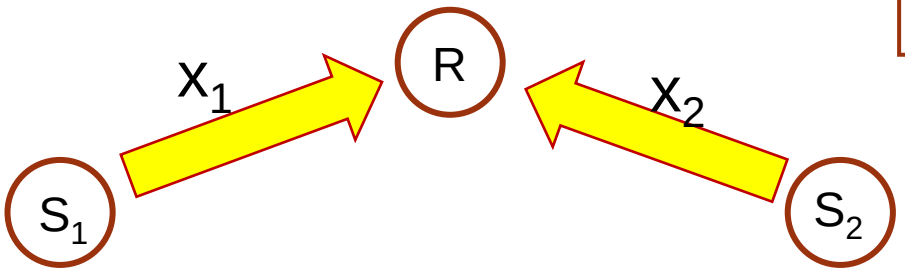
$$y_R = \sqrt{P_1} \cdot h_{S1,R} \cdot x_1 + \sqrt{P_2} \cdot h_{S2,R} \cdot x_2 + \omega_{S,R}$$

The received signal of relay node

The transmitted power

The transmitted symbols

Additive white Gaussian noise (AWGN)

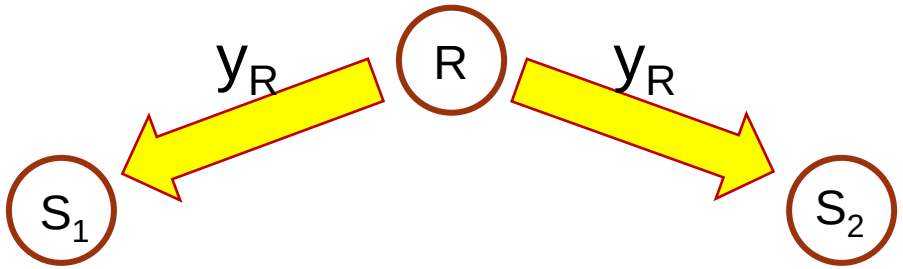


Relay protocol and modulation schemes

- R $\rightarrow$ {S_1, S_2}

$$y_{S1} = \sqrt{P_R} \cdot \beta \cdot h_{R,S1} \cdot y_R + \omega_{R,S1}$$

$$y_{S2} = \sqrt{P_R} \cdot \beta \cdot h_{R,S2} \cdot y_R + \omega_{R,S2}$$



Relay protocol and modulation schemes

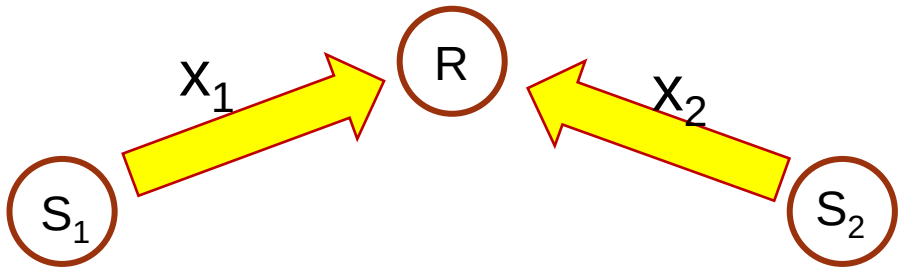
- β is the normalization factor which depends on $h_{S1,R}$ and $h_{S2,R}$ that are known at the relay node, but not at the two sources (S_1 and S_2).
- Channel coefficients, $h_{S1,R}$ and $h_{S2,R}$, need to be available in S_1 and S_2, which increase the payoff of information transmission.

Relay protocol and modulation schemes

- Decode-and-Forward (DF) :
  - $S_1 \rightarrow R : x_1$; $S_2 \rightarrow R : x_2$

$$y_R = \sqrt{P_1} \cdot h_{S1,R} \cdot x_1 + \sqrt{P_2} \cdot h_{S2,R} \cdot x_2 + \omega_{S,R}$$

  - And then decodes y_R to x_R
  - Finally, relay node encodes x_R to $\hat{x}_R$ to broadcast

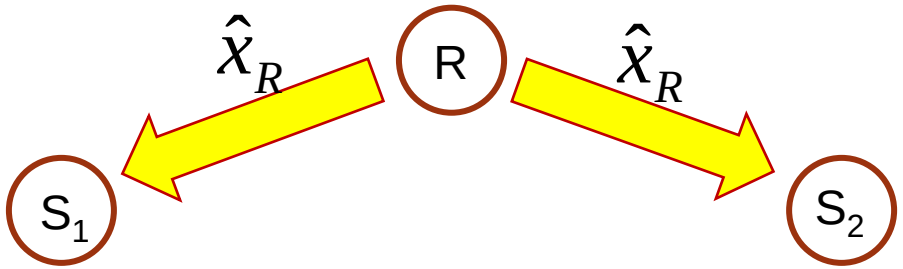


Relay protocol and modulation schemes

- $R \rightarrow \{S_1, S_2\}$: $x_R = x_1 \oplus x_2$

$$y_{S1} = \sqrt{P_R} \cdot h_{R,S1} \cdot \hat{x}_R + \omega_{R,S1}$$

$$y_{S2} = \sqrt{P_R} \cdot h_{R,S2} \cdot \hat{x}_R + \omega_{R,S2}$$



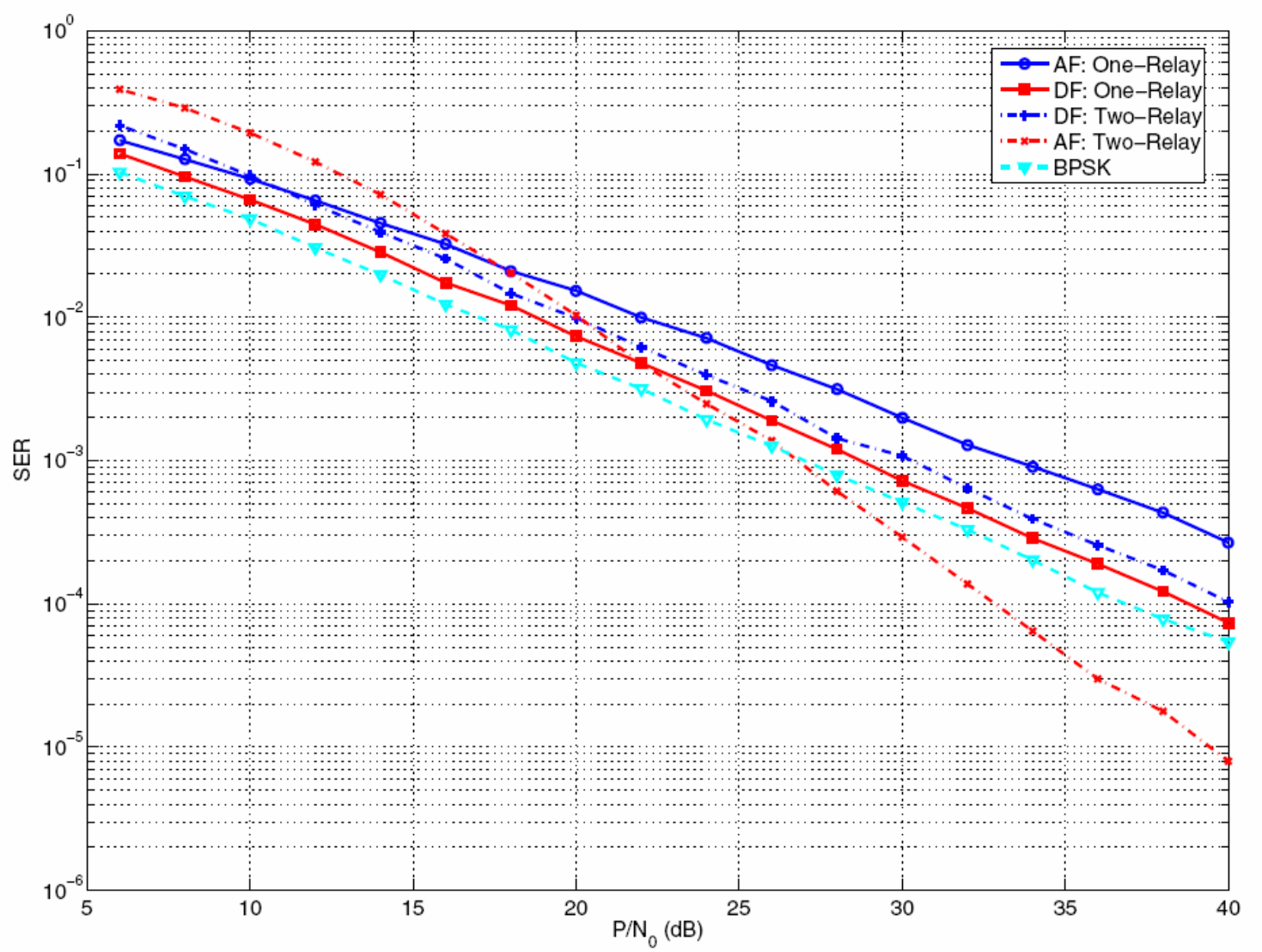
Relay protocol and modulation schemes

- The new decode-and-forward removes the transmission of channel coefficients in step 1 $h_{S1,R}$ *and* $h_{S2,R}$.
- It also demonstrates better performance than the amplify-and-forward scheme, which will be clear in simulation.

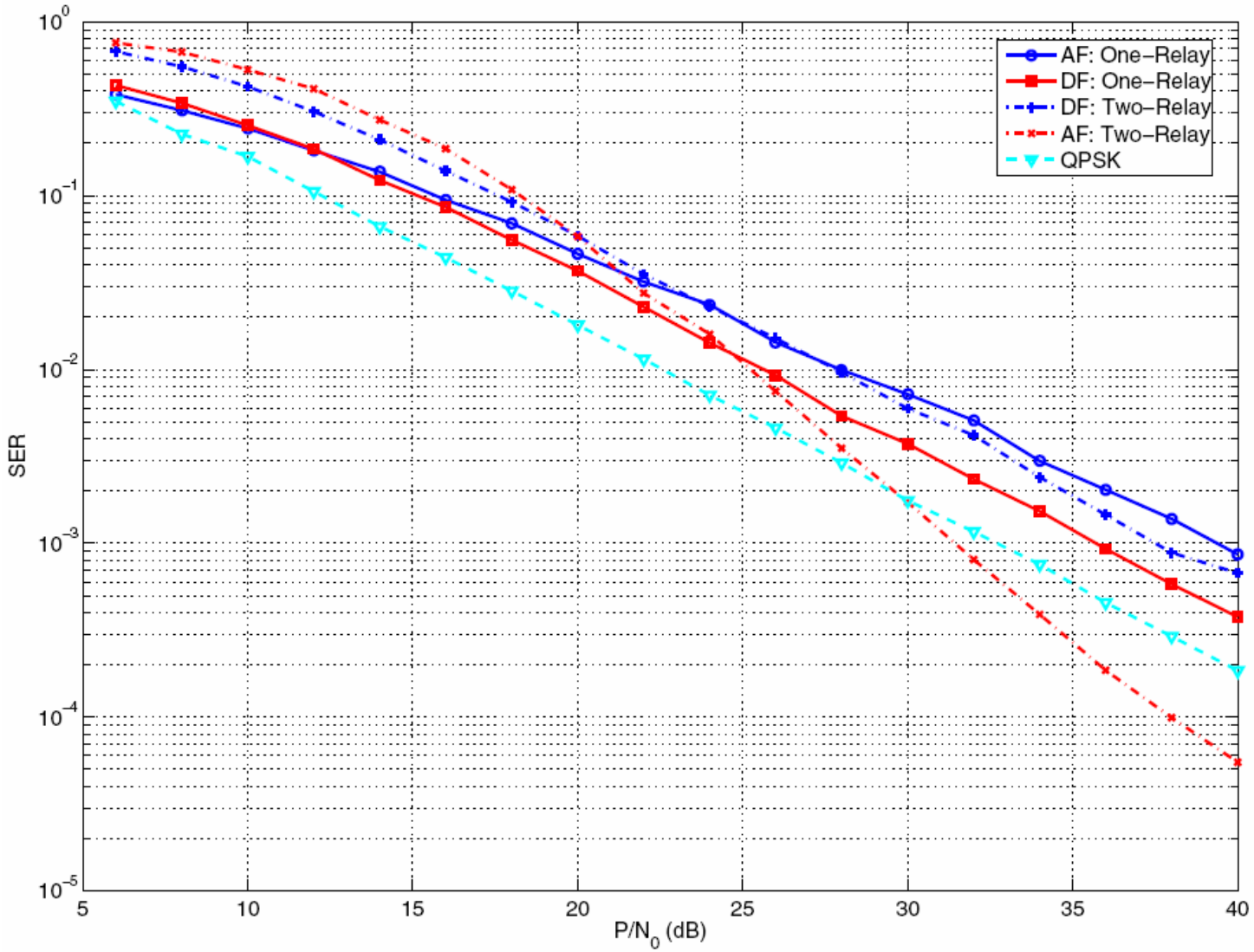
Relay protocol and modulation schemes

- For the two relays system, there are some different with one relay system：
  - It uses orthogonal space-time block code (OSTBC) [10] to encode the signal to transmit.
  - But it assumes the perfect synchronization between R_1 and R_2.
  - For DF, the two relay nodes decode the signal from S_1 and S_2 with OSTBC, and encode it to another signal with OSTBC, increase BER.

Simulation


AF: One–Relay
DF: One–Relay
DF: Two–Relay
AF: Two–Relay
BPSK
SER
P/N0 (dB)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
5
10
15
20
25
30
35
40

Simulation


AF: One–Relay
DF: One–Relay
DF: Two–Relay
AF: Two–Relay
QPSK
SER
P/N0 (dB)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
5
10
15
20
25
30
35
40

Conclusions

- This paper investigates the performance of cooperative communication and network coding together.
- It also presents a new decode-and-forward scheme for one relay system.
- The future work on the cooperative network coding includes the power optimization between the two steps transmission and generalization to multi-hop communication.